Quantifying the uncertainties in CERES SYN1deg Arctic surface radiative fluxes with the MOSAiC field campaign

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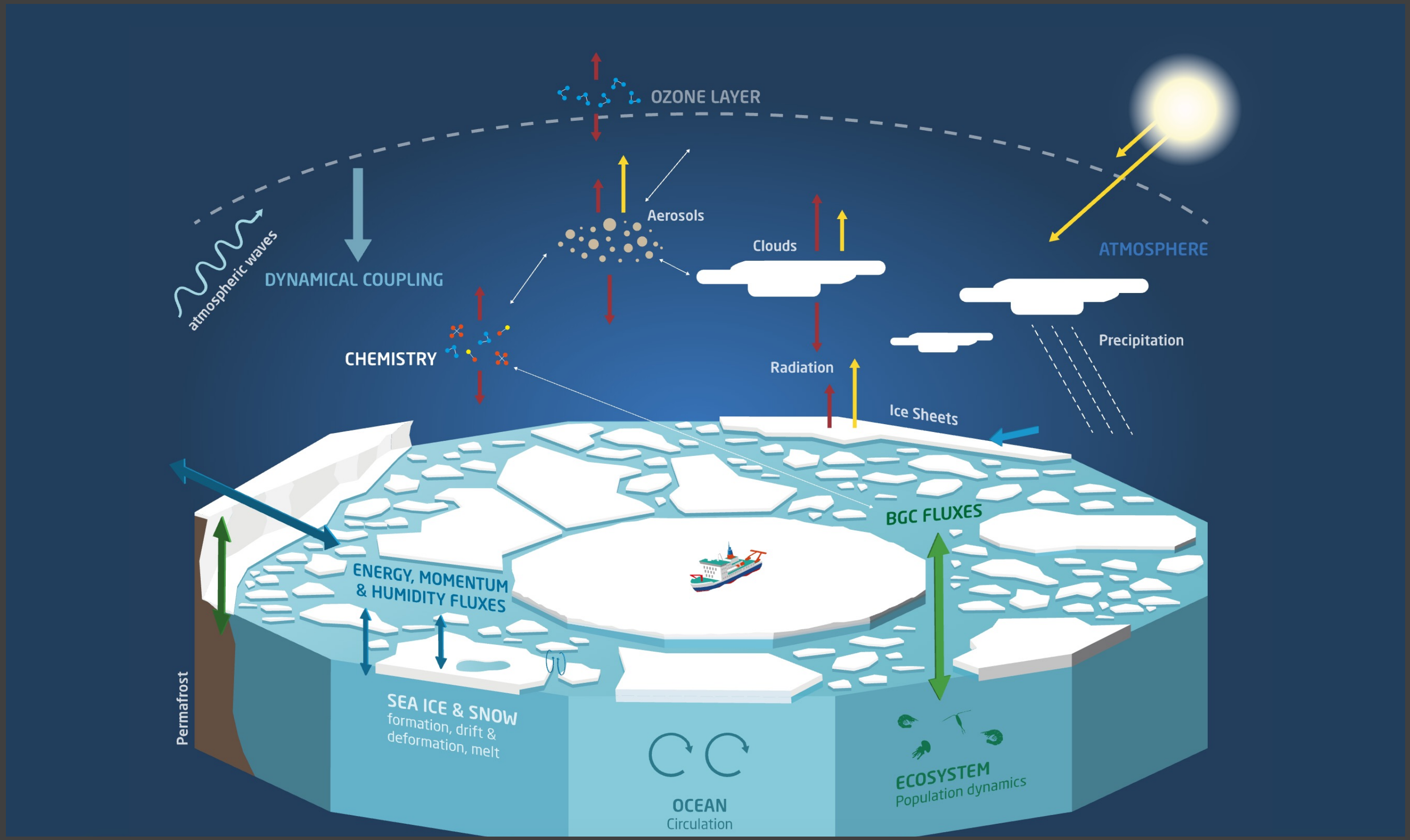
The Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) field campaign

September 2019 - October 2020

- The largest polar expedition in history; the first time in polar winter
- The goal of the MOSAiC expedition was to take the closest look ever at the Arctic as the epicenter of global warming and to gain fundamental insights that are key to better understand global climate change



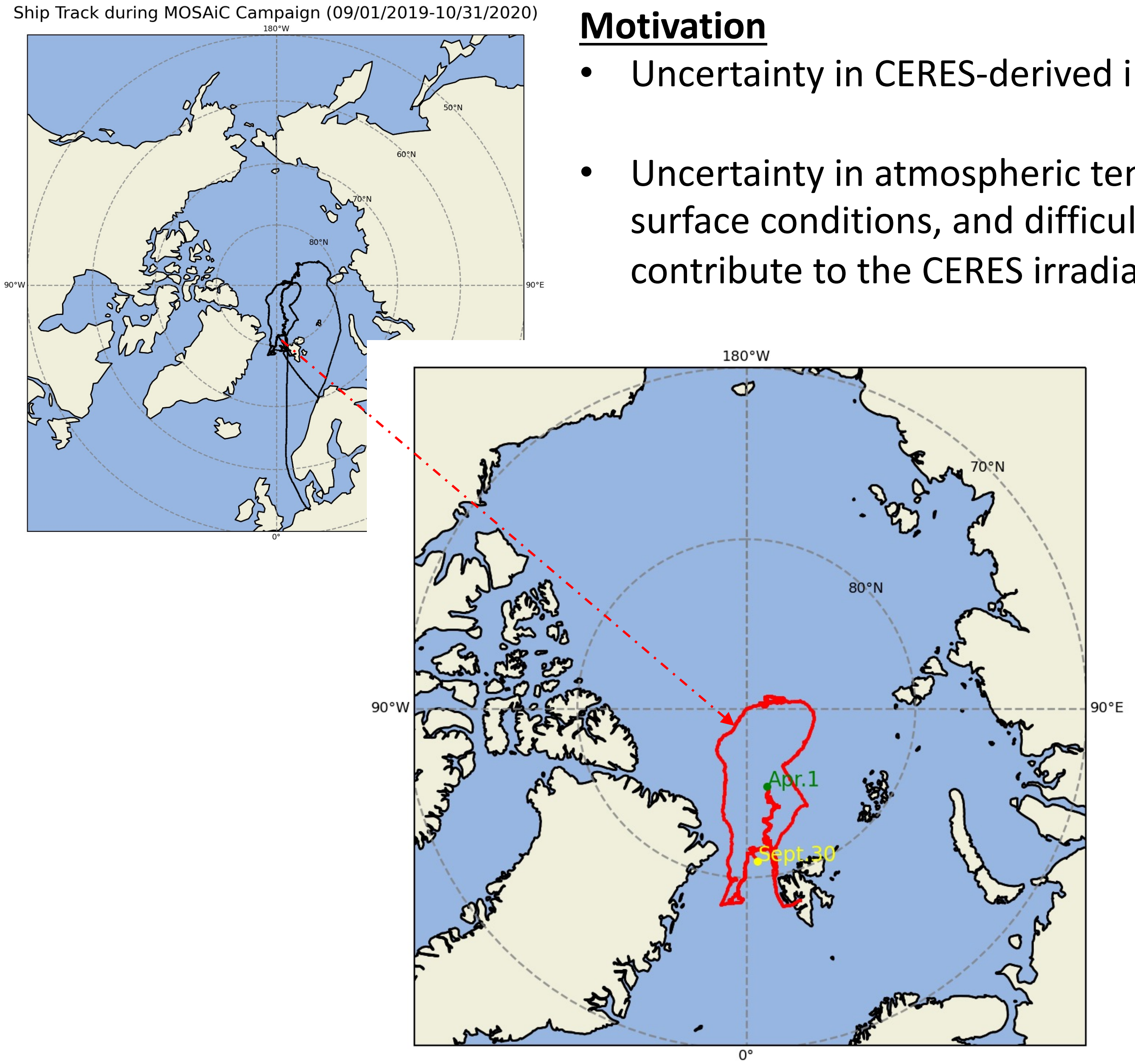
https://mosaic-expedition.org/

Overview

Motivation

- Uncertainty in CERES-derived irradiances is larger over sea ice than any other scene type

- Uncertainty in atmospheric temperature and humidity from reanalysis, heterogeneity in surface conditions, and difficulties in detecting and characterizing clouds over sea ice all contribute to the CERES irradiance uncertainty



Outline

- The comparison between CERES SYN1deg and MOSAiC from April to September 2020

- The surface albedo perturbation experiments with Fu-Liou radiative transfer model

MOSAiC remote flux stations (managed by CIRES/NOAA)

- **Multiple remote flux stations**: asfs30, asfs40, asfs50
- **Temporal resolutions**: 10s
- **Location**: top of station at 2 m

Measurements at surface
solar zenith angle, solar azimuth angle, snow depth, air pressure, air temperature, relative humidity, dew point temperature, mixing ratio, absolute humidity, vapor pressure, brightness temp, surface skin temp, conductive flux, wind speed, wind direction

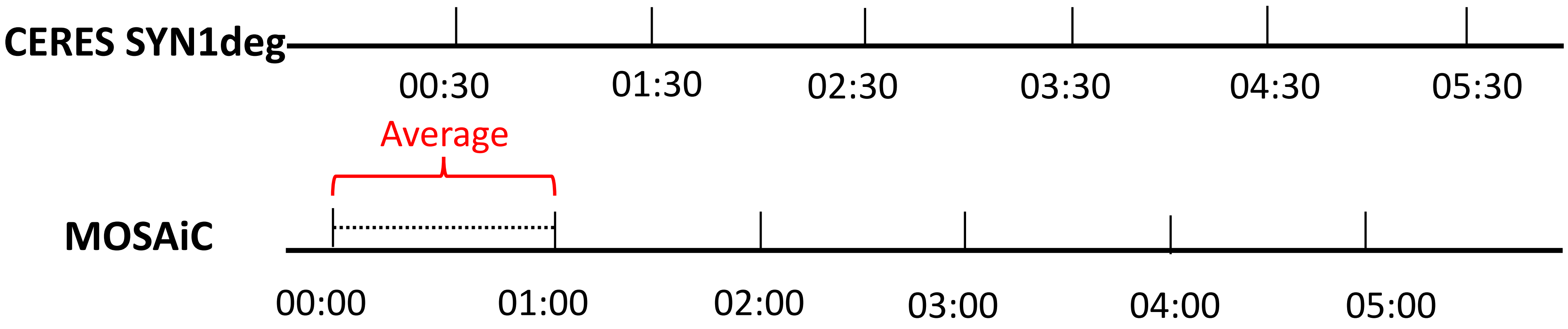
Turbulence and met tower (2m, 6m, 10m, 24m)
Latent heat flux, Sensible heat flux
Temperature

Radiation measurements

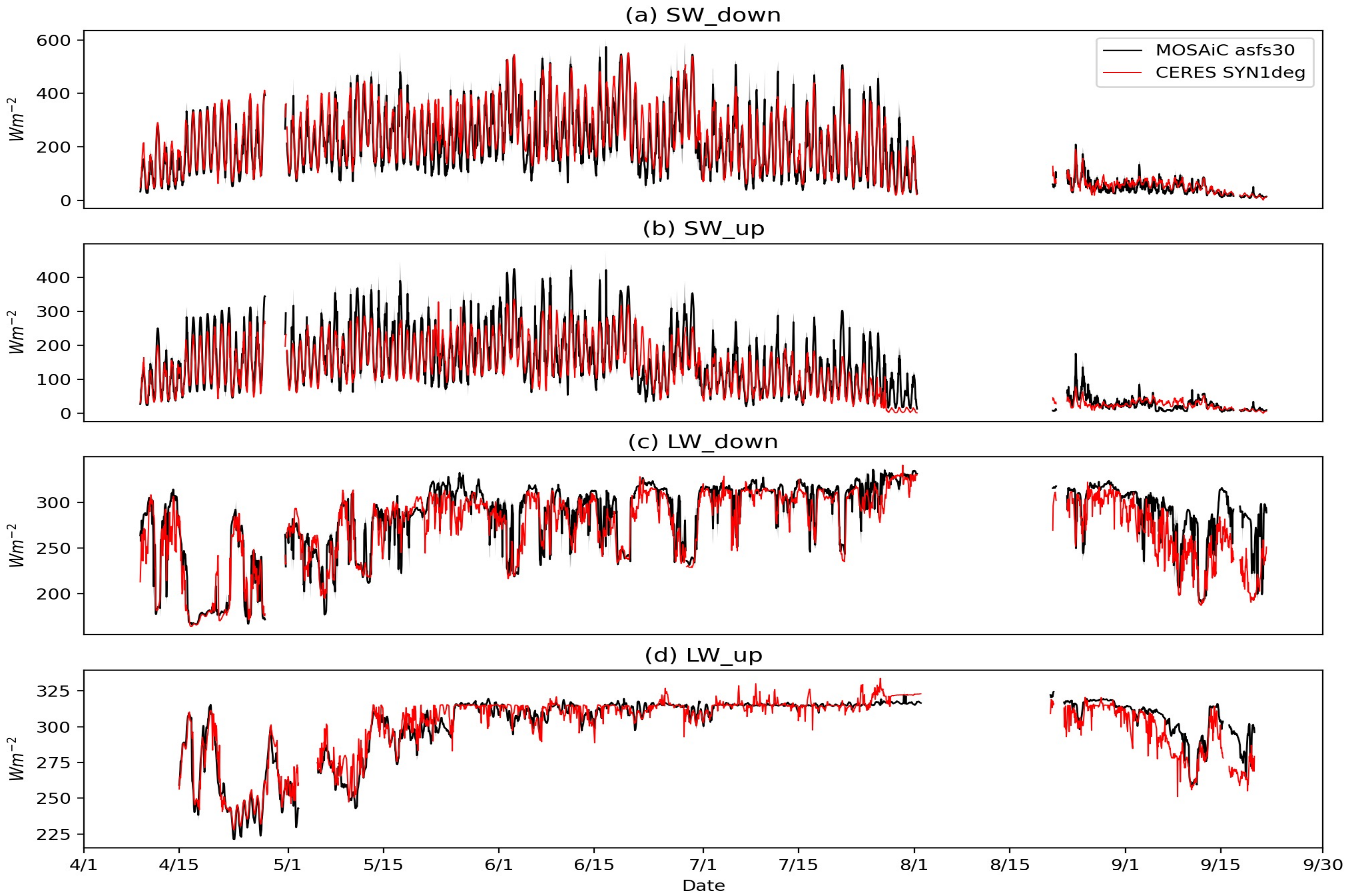
Variable	Instrument
SW_up flux	Hukseflux SR30 pyranometer
SW_down flux	Hukseflux SR30 pyranometer
LW_down flux	Hukseflux IR20 pyrgeometer
LW_up flux	Hukseflux IR20 pyrgeometer
Net radiative flux	SR30 and IR20 radiometers

Collocation between CERES SYN1deg and MOSAiC

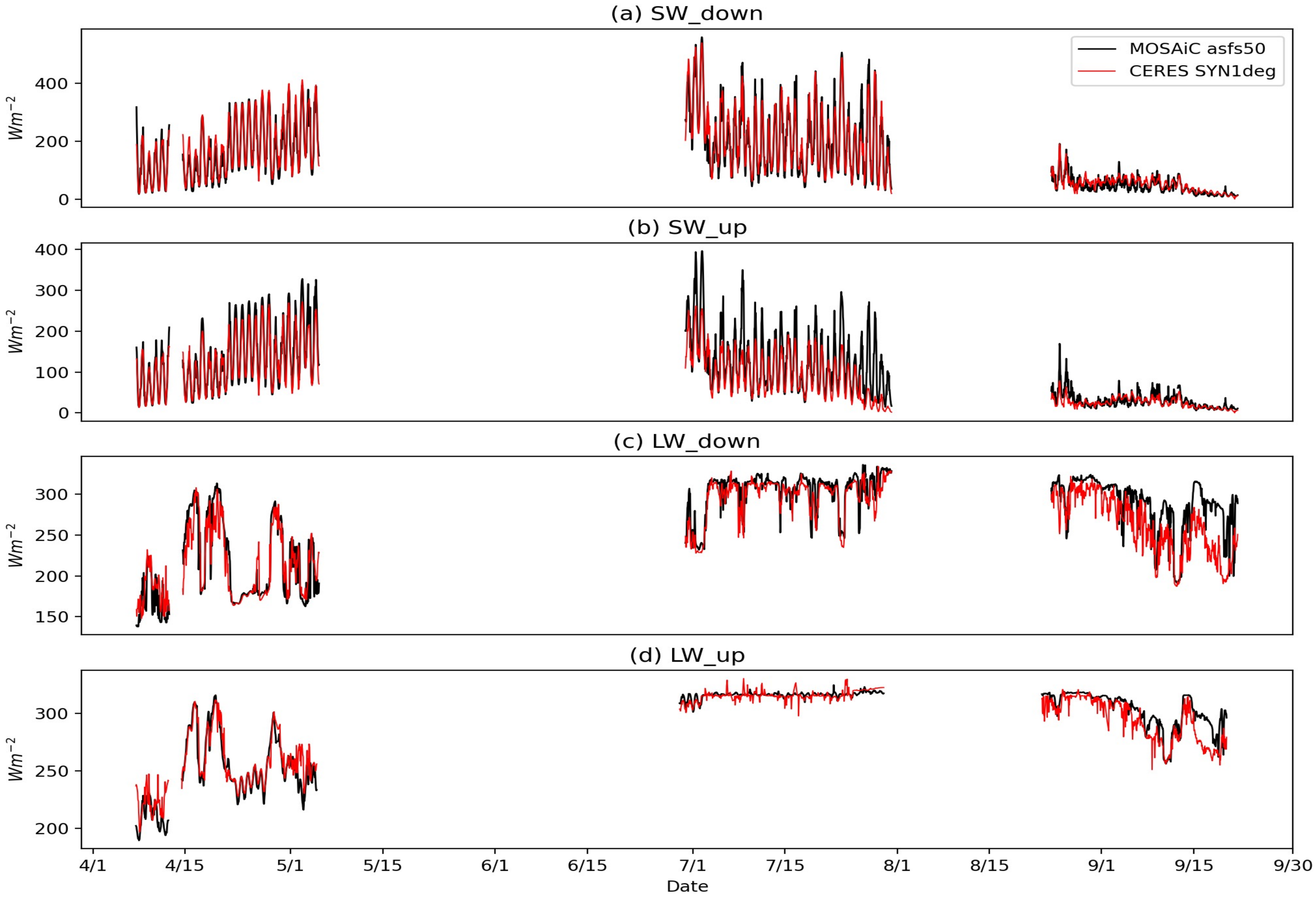
- **CERES**: CERES_SYN1deg-1H_Terra-Aqua-MODIS_Ed4.1 (Hourly)
- **MOSAiC**: mosasfsmet.level2.10min (10-min)
- Averaged 10-min MOSAiC data (location, radiative fluxes) and saved it as hourly output and collocated hourly data with CERES SYN1deg dataset



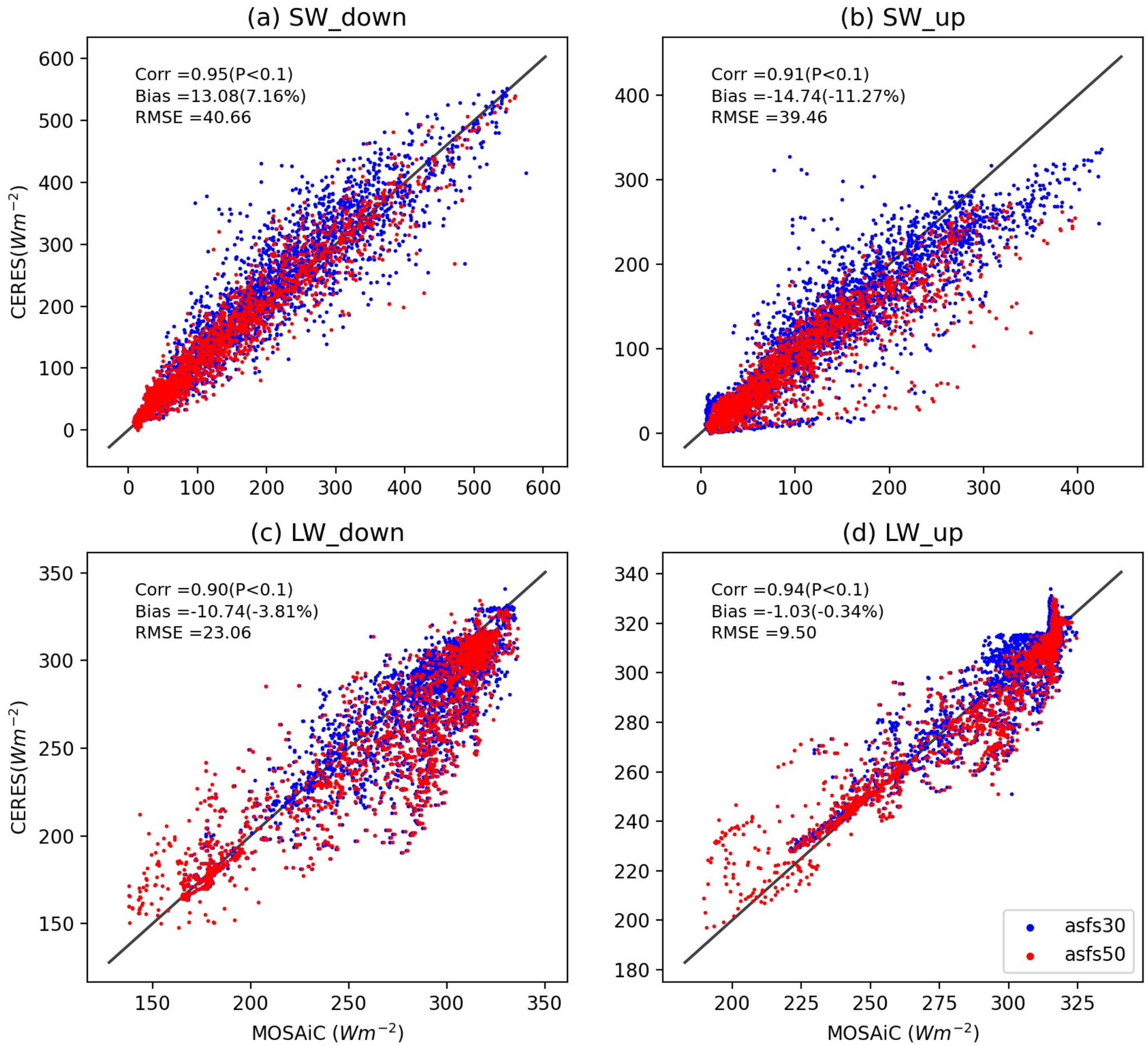
Radiative fluxes at the surface: MOSAiC asfs30 and CERES SYN1deg



Radiative fluxes at the surface: MOSAiC asfs50 and CERES SYN1deg

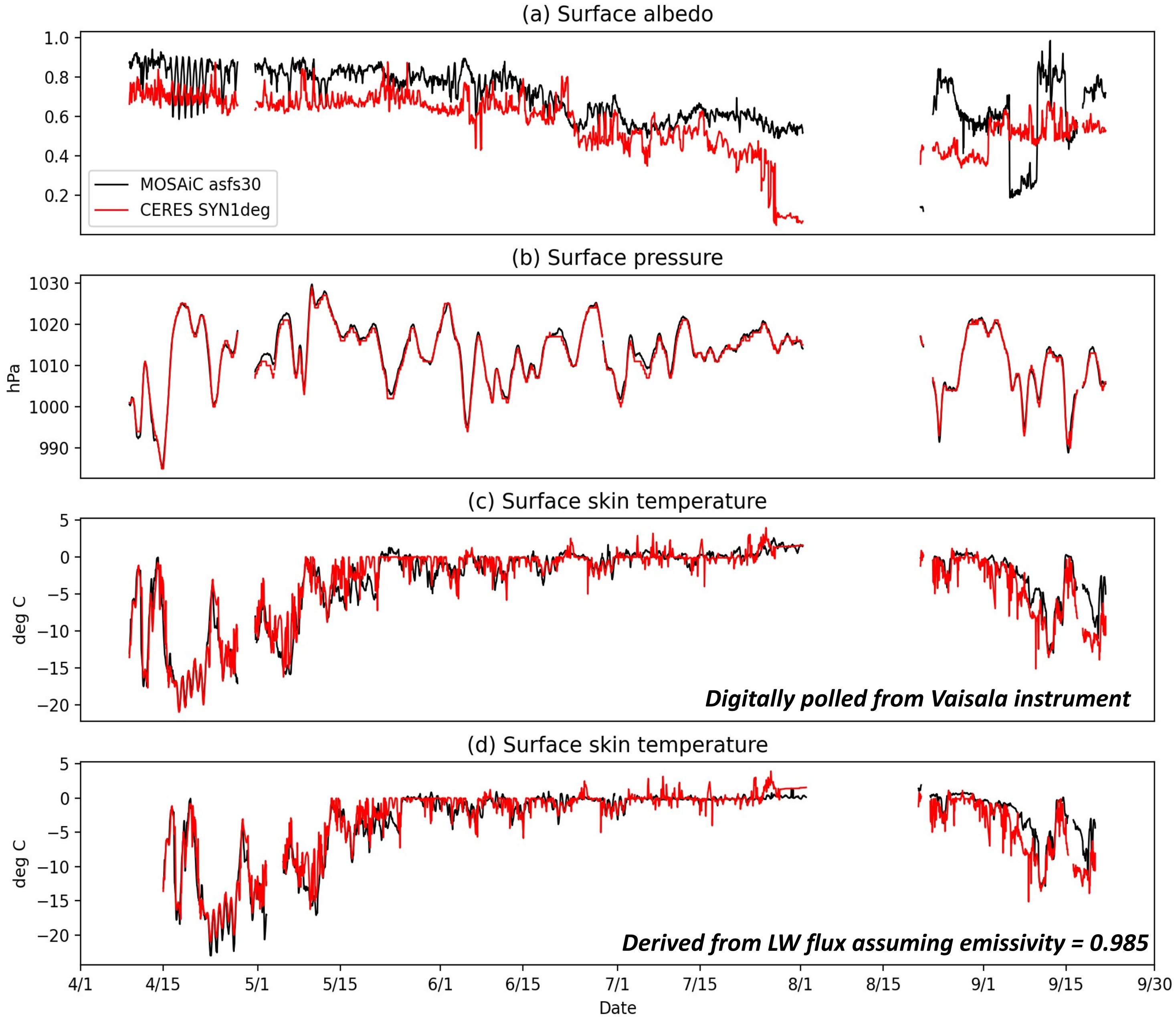


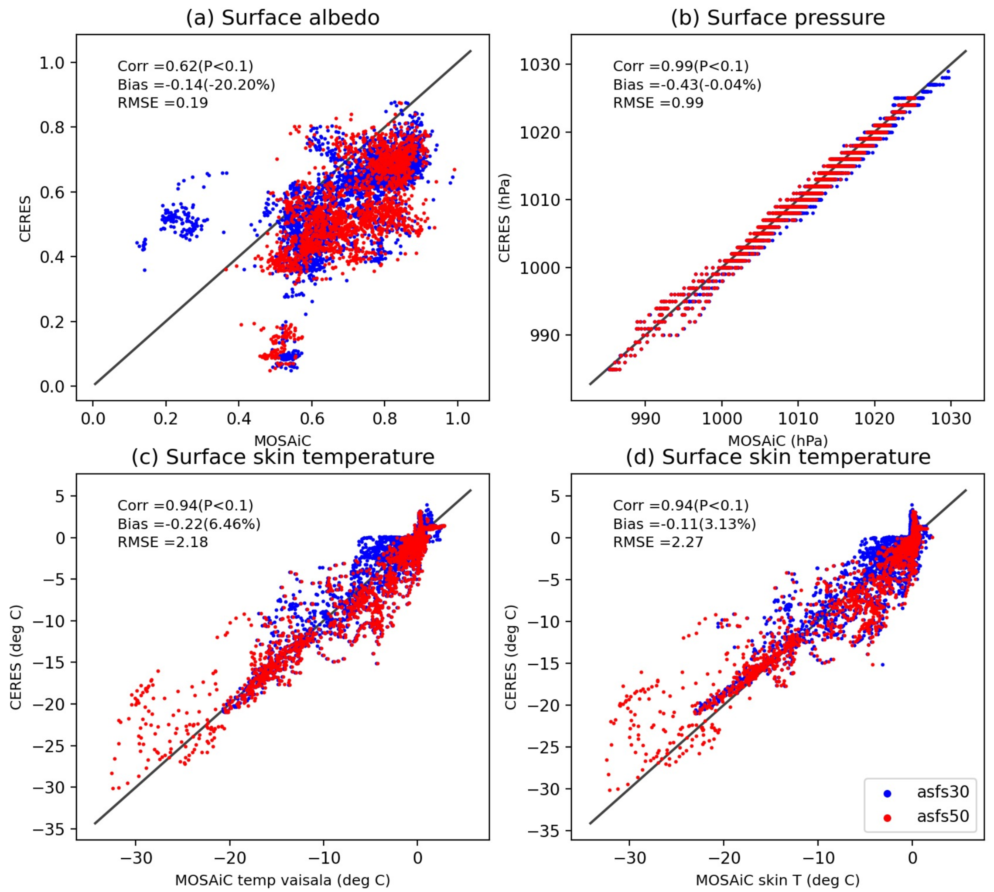
Radiative fluxes at the surface: MOSAiC and CERES SYN1deg



- The SYN1deg tends to overestimate SW_down flux, but underestimate SW_up and LW_down fluxes at the surface during summertime
- The SW_up flux is the most uncertain quantity
- Larger uncertainty with LW_up flux (~320W/m^2) when the surface reaches melting point

Meteorological conditions: MOSAiC and CERES SYN1deg





- The SYN1deg constantly underestimates the surface albedo during summertime
- Large uncertainty remains in surface skin temperature when surface reaches melting point (~0°C)

What if we correct CERES surface albedo bias using MOSAiC data?

CERES-like Fu-Liou RTM calculations

Category	Variables	Sources
General model inputs	Number of model layers	4 layers
	Solar zenith angle	TSI files
	Solar insolation	Daily SORCE TSI files and earth-sun distance
	Solver method	**4-stream solver for SW and LW calculation**
	Other information (CO2,CH4,N2O, CFCs, correction to cosSZA, etc)	Values in year 2019
Atmospheric structure inputs	Pressure profile	MOA files (GEOS-5.4.1)
	Air temperature profile	
	Water vapor mixing ratio profile	
	Ozone mixing ratio profile	
	Surface skin temperature	
Cloud inputs	Cloud fraction, effective radius, optical depth, phase, particle size	TSI files (from MODIS)
Surface inputs	Spectral surface albedo	**JIN lookup table, daily sea ice concentration, and monthly Terra surface albedo history (SAH) map**
	Spectral surface emissivity	Determined by surface type
Aerosol inputs	Aerosol types and aerosol optical depth	MATCH aerosol hourly output

SYN1deg Ed4
Gamma-weighted Two-stream approximation (GWTSA)

SYN1deg Ed4
Terra/Aqua SAH monthly map

Surface spectral albedo calculations in the RTM

Obtain the Ocean and Sea ice spectral albedos using Jin LUTS

Combine ocean and ice albedo by weighting by scene fractions

Determine an approximate broadband albedo for the combined initial spectral albedo

Normalize to the SAH based hourly broadband albedo

SAH_OHS

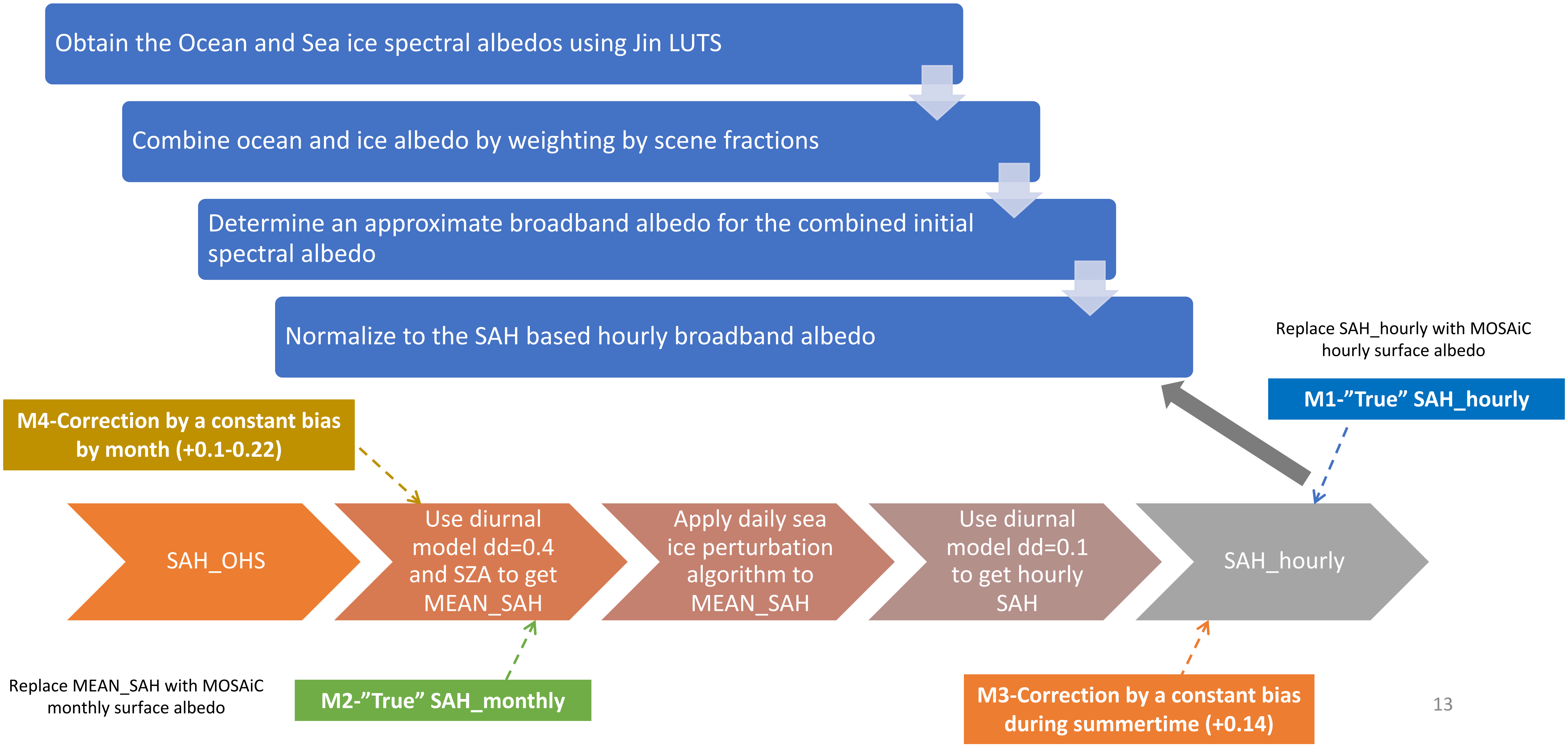
Use diurnal model dd=0.4 and SZA to get MEAN_SAH

Apply daily sea ice perturbation algorithm to MEAN_SAH

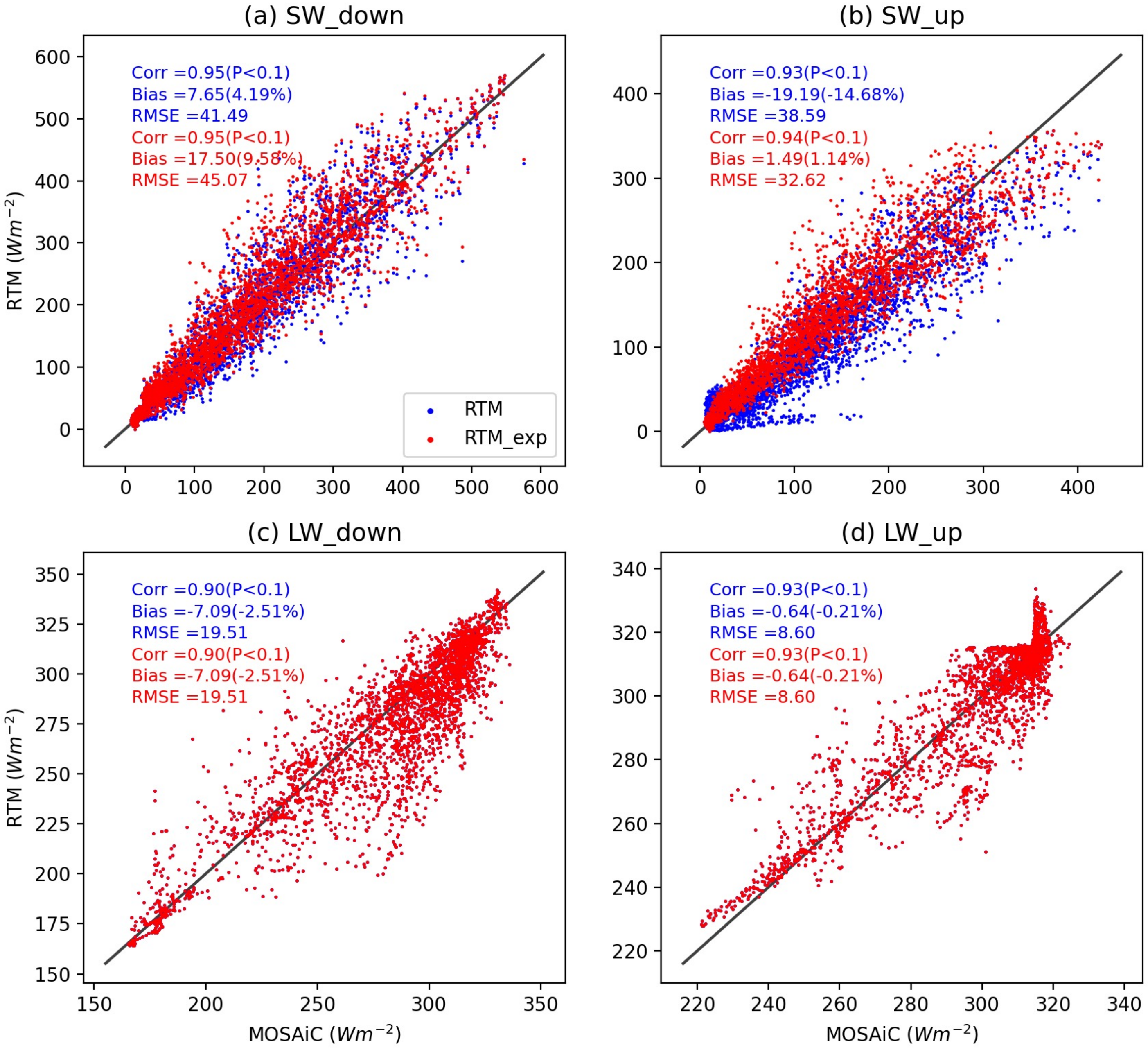
Use diurnal model dd=0.1 to get hourly SAH

SAH_hourly

Surface spectral albedo calculations in the RTM



Surface spectral albedo calculations in the RTM – Method 1



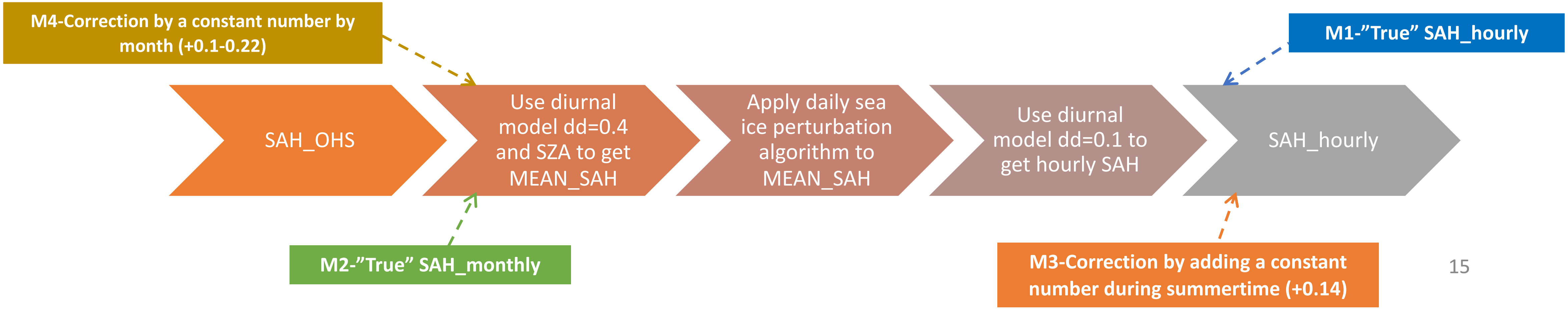
- The uncertainty in SW_up flux was reduced by ~15%, while the uncertainty in SW_down flux was increased by ~8% (RMSE)

- No impacts on LW fluxes

The SW differences between RTM and MOSAiC (%)

Experiment	SW_down	SW_up
Control run	+4.19%	-14.68%
M1-"True" SAH_hourly (relative to control run)	+9.58% (+5.39%)	+1.14% (+15.82%)
M2-"True" SAH_monthly (relative to control run)	+14.26% (+10.07%)	-1.96% (+12.72%)
M3-correction by a constant summertime bias (relative to control run)	+9.08% (+4.89%)	**+3.08% (+17.76%) -the largest change**
M4-correction by a constant bias by month (relative to control run)	+8.52% (+4.33%)	**+1.03% (+15.72%) -the most accurate**

- Compared to M1 and M2, the monthly surface albedo history (SAH) bias contributes to ~**80**% of uncertainty in SW_up, while daily sea ice perturbation process accounts for ~**20%** of uncertainty
- Correcting SAH monthly map by adding a constant number would be an efficient strategy to reduce SW_up biases during summertime
- The impacts of multiple reflections between clouds and highly reflective surface should be taken into consideration



Summary

- The SYN1deg tends to overestimate SW_down flux, but underestimate SW_up and LW_down fluxes at the surface during summertime
- The large negative bias in SW_up flux can be attributed to the underestimation of surface albedo in SYN1deg
- Correcting SAH monthly map by adding a constant number would be an efficient strategy to reduce SW biases during summertime
- It is important to consider the impacts of cloud biases (multiple reflection between clouds and reflective surface) when correct the surface albedo
- Larger uncertainty with LW_up flux (~320W/m^2) when the surface reaches melting point (~0°C)
- The biases in surface wind and surface water vapor mixing ratio show a minor impact on SW and LW flux calculations

Photo credit: https://blogs.helmholtz.de/polarstern/en/2019/09/anchors-aweigh-for-mosaic-leg-1/